PHENIX results on heavy flavor production in $p + p$ and Au+Au collisions at RHIC

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Abstract

In relativistic $p + p$ collisions, heavy flavors provide a tool to test perturbative Quantum Chromo-Dynamics (pQCD) calculations since they are produced at the early stage of the collision via hard processes involving large momentum transfer and are thus well suited to such calculations. On the other hand, in heavy ion collisions heavy flavors help advance our understanding of in-medium quark energy loss mechanisms on top of what has been learned using light quarks.

This presentation discusses the latest results from PHENIX on heavy flavor mesons production in $p + p$ and Au+Au collisions at a center of mass energy per nucleon-nucleon collision $\sqrt{s_{NN}} = 200$ GeV, as well as measurements that separate charm and beauty contributions versus transverse momentum, p_{T}, in $p + p$ collisions.

The PHENIX experiment [1] has measured charm and beauty production in $p + p$ collisions at a center of mass energy $\sqrt{s} = 200$ GeV by studying the production of single leptons and removing all contributions that are not from heavy flavor meson semi-leptonic decays [2]. At mid-rapidity ($|y| < 0.35$), single electrons are measured and the background is dominated by π and η Dalitz decays as well as photon conversions. These contributions are estimated using two methods. The first consists of adding a known amount of material in the detector acceptance and measuring how the production is affected. This allows a direct measurement of the photon conversion contribution. The second method uses data-driven simulations of all background contributions to form a hadron *cocktail* that is statistically subtracted from the data. Results agree reasonably well with fixed order and next-to-leading-log (FONLL) calculations [3] and give a total charm cross section $\sigma_{c\bar{c}} = 567 \pm 57^{\mathrm{stat}} \pm 224^{\mathrm{syst}}$ μb.

A similar cocktail-based method is used at forward rapidity ($1.5 < |y| < 1.9$) with the PHENIX muon arms to measure heavy flavors from single muon production. Cathode Strip chambers are used for momentum determination in the magnetic field and five layers of alternating detection planes and steel absorbers are used for particle identification. Background contributions are estimated using simulations tuned to the data notably by

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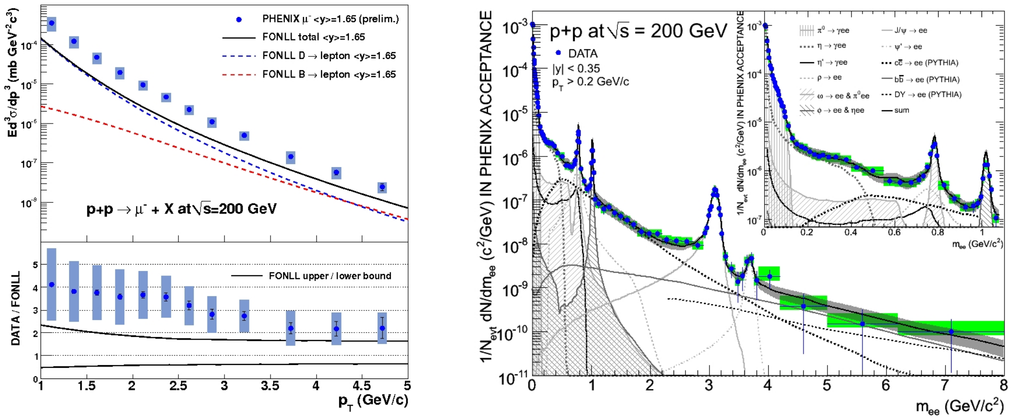

Fig. 1. Left: Heavy flavor invariant cross section as a function of lepton (from semi-leptonic decays) p_{T} at forward rapidity in $p+p$ collisions. Solid lines correspond to FONLL calculations and theoretical uncertainties. Right: di-electron invariant mass distribution in $p+p$ collisions at mid-rapidity. The lines represent all known contributions to the spectrum estimated using either independent measurements or simulations and fitted to the data.

studying the vertex z distribution of the reconstructed tracks and measuring hadrons that stop in the third or fourth layers of the muon identifier. Resulting invariant cross sections as a function of the lepton transverse momentum (p_{T}) are shown in Fig. 1 (left), together with recent FONLL calculations. The measured differential cross sections are consistently above the calculations, although the difference becomes smaller with increasing p_{T} ($p_{\mathrm{T}} > 3.5$ GeV/c), where the signal over background is improved and the FONLL calculations become more reliable. On the other hand, the p_{T} spectrum is softer than the one measured at mid-rapidity, a feature that is qualitatively reproduced by these calculations.

The study of the invariant mass distribution of di-lepton pairs constitutes a largely independent measurement of heavy flavor production, provided that all other contributions to this distribution are identified and removed. This includes resonances, π and η Dalitz decay, etc. Open charm contribution dominates at intermediate mass range ($m \in [1, 2.5]$ GeV/c^2), whereas open beauty and Drell-Yan contributions dominate at high mass($m > 4$ GeV/c^2), as shown in Fig. 1 (right), for di-electrons produced at mid-rapidity. The charm production cross section measured using this method ($\sigma_{c\bar{c}} = 544 \pm 39^{\mathrm{stat}} \pm 142^{\mathrm{syst}}$ μb) [4] agrees well with the published single-electron result.

Single lepton measurements do not allow separation of the contributions from charm and beauty. This separation is achieved independently by counting the number of unlike-sign electron-hadron pairs coming from heavy flavor weak decay, and comparing it to the total number of measured heavy flavor (estimated as above) to form so called *pair efficiency*. This efficiency differs between D and B for kinematic reasons and can be evaluated for each flavor separately with simulations. This difference allows an estimate of both contributions to the measured *unidentified* efficiency. The resulting beauty over charm+beauty ratio is shown in Fig. 2 (left) at mid-rapidity, as a function of the electron p_{T}. It agrees with recent FONLL calculations, but both experimental and theoretical uncertainties are large.

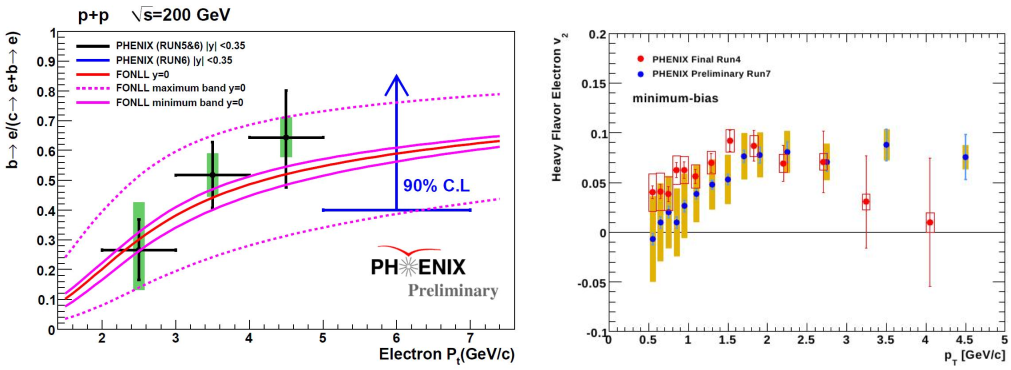

Fig. 2. Left: ratio of beauty over charm+beauty production as a function of the decay electron transverse momentum in $p+p$ collisions at $\sqrt{s} = 200$ GeV. Solid lines correspond to FONLL calculations and uncertainty. Right: Elliptic flow v_2 of electrons from heavy flavor mesons semi-leptonic decay in Au+Au minimum bias collisions at mid-rapidity. Published (red symbols) and updated preliminary results (blue symbols) are shown.

In Au+Au collisions, heavy flavor production yield is measured using the same technique as in $p+p$. It is combined with the yield in $p+p$ collisions to form the nuclear modification factor R_{AA}. A significant reduction of R_{AA} is observed at mid-rapidity for central collisions and high p_{T} [5]. This results from strong interactions of the heavy quarks with the medium produced during the collision. Studying the azimuthal anisotropy of the electrons coming from heavy flavor mesons semi-leptonic decay with respect to the collision reaction plane provides another tool to study these interactions. This anisotropy is characterized by the elliptic flow parameter v_2. The measured v_2 as a function of the electron p_{T} for minimum-bias Au+Au collisions at mid-rapidity is shown in Fig. 2 (right). The published results, using PHENIX 2004 data [5], are compared to the new measurement performed in 2007 with a higher statistics data sample and a more precise determination of the collision reaction-plane. The measurements are in good agreement and exhibit a large positive elliptic flow for $p_{\mathrm{T}} > 2$ GeV/c. This poses a challenge to existing energy loss mechanisms due to the large mass of the heavy quarks and the predicted dead-cone effect [6]. No theoretical consensus has been achieved to date, although some calculations can describe the data fairly well [7].

A more precise understanding of heavy flavor production in relativistic $p+p$ and heavy ion collisions requires larger data samples, understanding of cold nuclear matter effects (by studying e.g. d+Au collisions), and more direct measurements (for instance using direct identification of heavy flavor mesons).

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